

Sensor Web Adaptive Resource Manager

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Abstract—Future spacecraft systems are likely to consist of distributed processes that dynamically respond to perceived scientific events, the spacecraft environment, spacecraft anomalies and user commands. In such complex and dynamic environments, a method to dynamically adapt the system to handle the dynamic conditions is needed. To address this, a sensor web adaptive resource management strategy, based on DeSiDeRaTa's resource management approach, is being evolved. The approach is being enhanced to characterize the dynamic aspects of intra-constellation network topologies and to accommodate multiple and heterogeneous types of workloads.

The integration of DeSiDeRaTa with ITOS, a ground based real-time system developed by the Real-Time Software Engineering Branch at NASA's Goddard Space Flight Center, is being carried out to demonstrate the effectiveness of the approach. DeSiDeRaTa delivers the required quality of service to the ITOS system by providing the features of dependability, scalability and real-time performance. A scenario to demonstrate adaptive resource management of the ITOS components has been developed and is being implemented to realize a ground based test bed for sensor webs. The test bed will be used to identify the critical issues involved in dynamically managing the distributed computing systems of spacecraft.

I. INTRODUCTION

Sensor Web Adaptive Resource Manager (SWARM) uses the DeSiDeRaTa adaptive resource management strategy [1] to realize the vision of re-configurable ground and space information systems. A sensor web can be imagined as an integrated constellation of satellites collectively monitoring the conditions of earth. SWARM aims at demonstrating the feasibility for adaptive resource management in a ground based command and control system and eventually providing a ground based test bed for these types of space systems. Further, achieving the ability to change the use of sensors at run-time and ultimately, optimizing the use of computing and network resources in the sensor webs are the other major goals of SWARM.

It is understandable that, to achieve the dynamic configuration of sensor webs and to meet the associated real-

time requirements, there is a need for real-time control software systems. To address this issue, the DeSiDeRaTa adaptive resource management approach is being evolved. DeSiDeRaTa provides a means to control the various essential processes and satisfy the Quality of Service (QoS) objectives of these systems with the use of a set of middleware mechanisms. The DeSiDeRaTa adaptive resource management strategy ensures the efficient utilization of resources and continuous availability of the system. In addition, it guarantees a timely response to external events. This approach is being enhanced to (i) accommodate the dynamic aspects of intra-constellation network topologies and (ii) dynamic numbers of workloads and heterogeneous types of workloads.

Towards achieving a ground based test bed, Integration Test and Operations System (ITOS) [3], a ground based real-time system has been identified for the demonstration of the effectiveness of the adaptive resource management approach. ITOS is a software suite developed for the control of spacecraft and spacecraft components during development, test and on-orbit operations. Presently, ITOS and DeSiDeRaTa are being integrated; this which will provide a ground-based test bed for the evaluation of constellation management techniques.

The next section explains the DeSiDeRaTa adaptive resource management approach, and describes the enhancements being made for managing sensor webs. Section III presents the plan for making the ITOS system distributed and adaptive. The demonstration scenario for the integration of ITOS and DeSiDeRaTa is detailed in section IV.

II. SENSOR WEBS ADAPTIVE RESOURCE MANAGEMENT APPROACH

This section describes the DeSiDeRaTa approach for managing distributed computing and network resources in order to meet the real-time performance requirements of mission-critical systems.

DeSiDeRaTa provides middleware services for handling dynamic distributed real-time systems that cannot be characterized *a priori*. These systems function in dynamic

environments that preclude the use of static characterization approaches. Further, they may have rigorous multi-dimensional QoS objectives, such as real-time, survivability and scalability. Also, their requirements may be determined as a function of the environment, further increasing the difficulty of engineering them. To supply the desired QoS in such a context, DeSiDeRaTa addresses the following aspects: (i) QoS requirements specification, (ii) QoS monitoring, (iii) dynamic QoS management, and (iv) benchmarking.

The DeSiDeRaTa approach to adaptive resource and QoS management is based on the dynamic path paradigm, which provides a convenient abstraction for capturing the characteristics of dynamic real-time systems. A dynamic path is typically made up of sensors, actuators and control software for performing detection, assessment and action. The paths may have timing constraints, widely varying dynamic behavior and may be scalable and fault tolerant. The DeSiDeRaTa QoS specification language specifies the real-time, scalability and dependability QoS. This specification is used by the dynamic QoS management system of DeSiDeRaTa, which includes components for instrumentation, assessment, prediction and allocation. Dynamic assessment of QoS synthesizes the instrumentation data to compute the appropriate QoS metrics, which characterize current and projected QoS. The detection of poor QoS activates the DeSiDeRaTa resource manager (RM) to perform resource discovery, QoS diagnosis and resource allocation.

Towards attaining the vision of SWARM – a real-time software system controlling a sensor web – the DeSiDeRaTa

network resource manager is being developed to provide the capability of handling dynamic network topologies. Moreover, the current techniques employed in DeSiDeRaTa, though include features for monitoring, diagnosis and recovery of real-time applications, do not include support for the real-time communication links that are typically present in a distributed system. In such systems, QoS violations may also be caused by communication links that fail to transfer data in a real-time fashion. The network resource manager detects these failures and performs resource reallocations to provide real-time performance.

In addition, enhancements to the RM strategy are being made to accommodate multiple data/event streams and heterogeneous types of data/event stream elements (which characterize the workload of the real-time system). This will be useful for the modeling and specification of dynamic systems that are driven by data from (1) multiple sensors and (2) sensors which monitor multiple types of phenomena.

III. INTEGRATION TEST AND OPERATIONS SYSTEM (ITOS) – RE-CONFIGURABLE STRATEGY PROTOTYPE

The feasibility of adaptive resource management will be demonstrated in the ground based ITOS real-time system. A typical ITOS ground data system configuration for spacecraft integration and test or on-orbit operations is shown in Fig. 1.

The ITOS configuration consists of a cluster of workstations interconnected over a local area network. Each workstation runs the complete ITOS software, with one designated as the primary operator console. This console

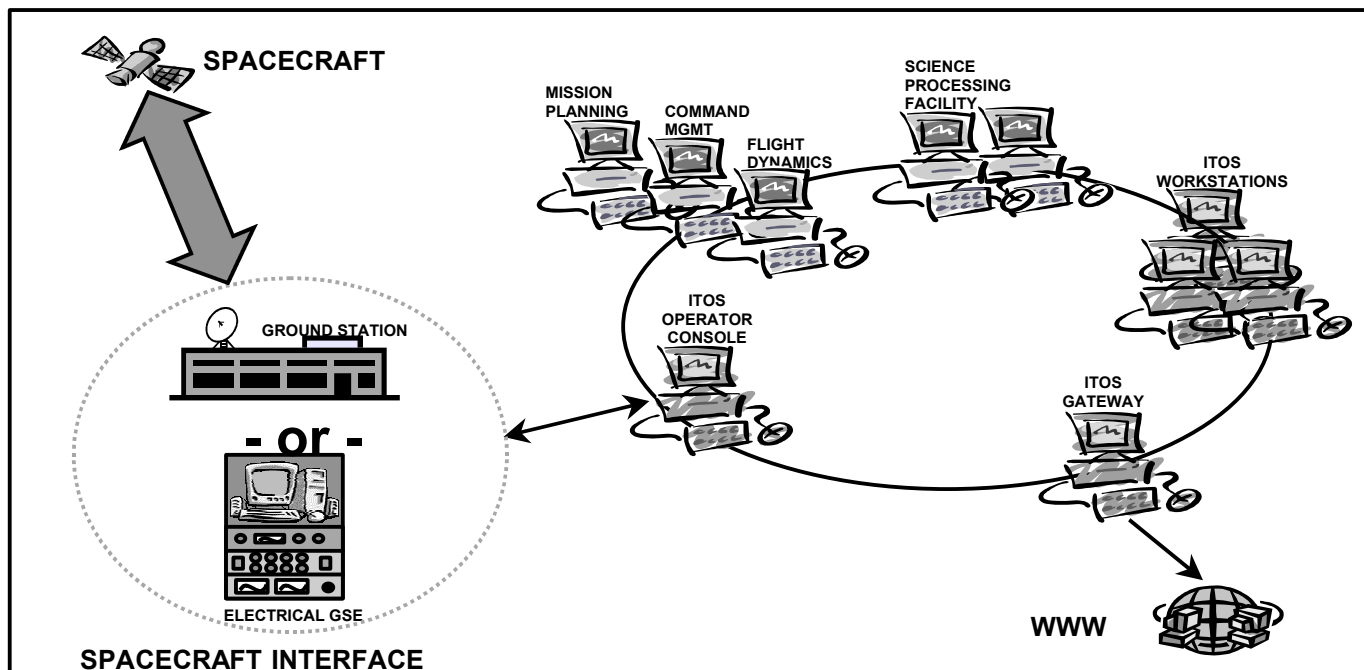


Fig.1. ITOS for spacecraft integration / on-orbit operations

receives telemetry data and sends commands to and from the spacecraft interface over an Ethernet connection. The primary console feeds the telemetry data it receives from the spacecraft interface to all other ITOS workstations. Each ITOS workstation unpacks the telemetry packets and performs data processing tasks such as limit checking, engineering unit conversions, and configuration monitoring. ITOS has an event subsystem, which recognizes spacecraft events, logs them, and forwards them to operators or external programs for processing. In addition, the primary ITOS console can distribute telemetry data via an IP Ethernet to other systems attached to the local area network; for example, the Science Processing Facility, Command Management System, Flight Dynamics System and Mission Planning System. This approach is analogous with the one to be taken within space-based sensor webs.

To show proof-of-concept, the resource management approach described in Section II is being applied to ITOS in the following steps:

1. Model the sensors, actuators, applications, and communication relationships within ITOS.
2. Construct a model of the dynamic real-time paths of ITOS.
3. Identify fault tolerance requirements.
4. Insert probes into ITOS applications (e.g., for events and resource usage).
5. Obtain resource usage profiles for the ITOS

applications and paths.

6. Specify the above properties in the DeSiDeRaTa QoS specification language.
7. Make applications scaleable and fault tolerant.
8. Deploy adaptive resource management for the application system.

IV. ITOS AND DESIDERATA INTEGRATION – DEMONSTRATION SCENARIO

Towards the application of resource management approach for ITOS, steps 1-3 (from section III) have been completed and the remaining steps have been partially completed. Fig. 2 shows the model of the dynamic real-time paths in ITOS; this was constructed by studying the sensors, actuators, applications and communication relationships within ITOS. The following systems and subsystems were identified within ITOS: event, telemetry, command, spacecraft test and operations language (STOL), frame sorter and display. These subsystems and systems include the following components (in the order of normal flow) as shown in Fig. 2:

- Frame sorter subsystem – *frame_input*, *vc_sorter*, *pkt_extract*, *archive*, *output*
- Display subsystem – *operational database (ODB)*,

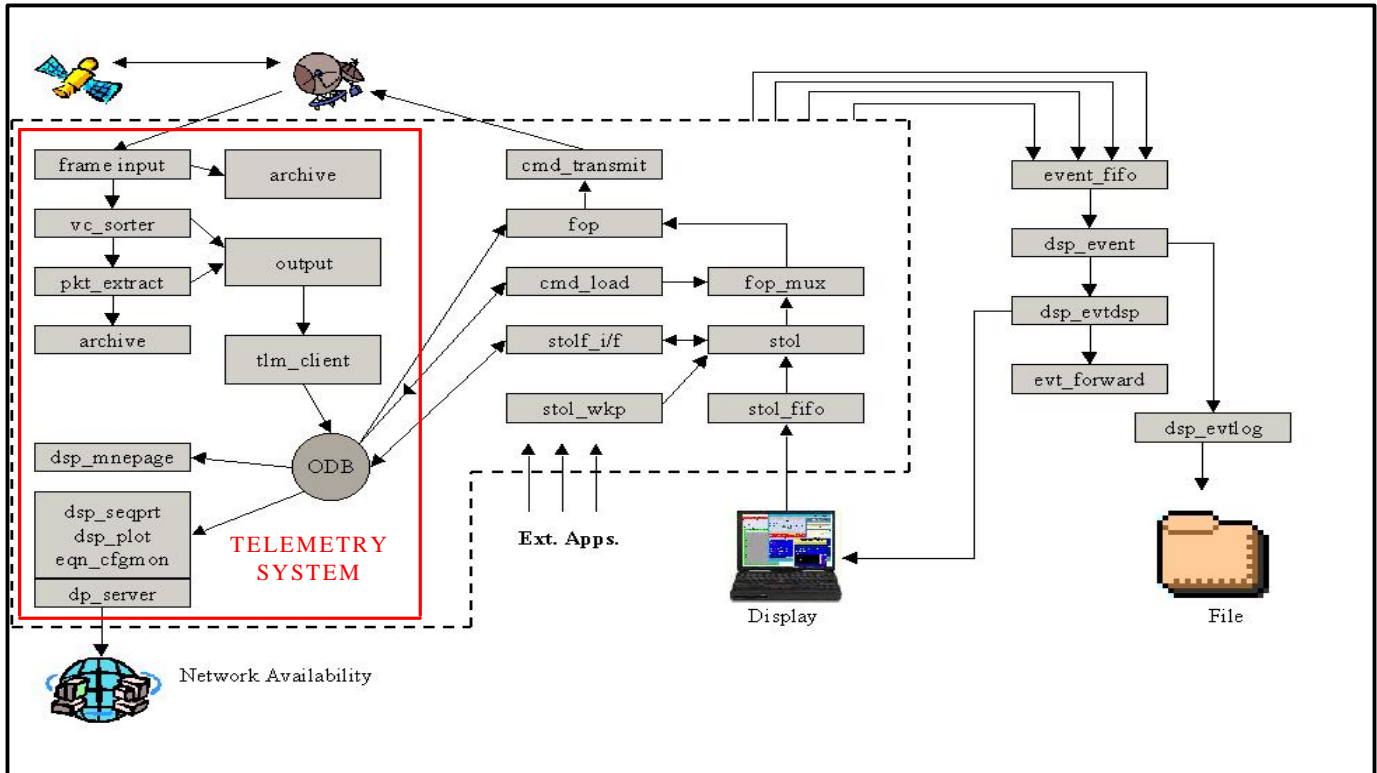


Fig. 2. Path model of ITOS

dsp_mnepage, dsp_seqprt, dsp_plot, eqn_cfgmon, dp_server

- Telemetry system – frame sorter subsystem, *tlm_client, ODB*, display subsystem
- Command system – *stol, cmd_load, ODB, fop_mux, fop, cmd_transmit*
- STOL system – *stol_fifo, stol_wkp, stol, stol_i/f, ODB*
- Event system – *event_fifo, dsp_event, dsp_evtlog, dsp_evtdsp, evt_forward*

The telemetry system, frame sorter subsystem and display subsystem were identified as the components that would be integrated with the resource manager and monitored for real-time performance. These systems were chosen because they carry the heaviest load. Specification files detailing the properties of the ITOS components were then created using the DeSiDeRaTa QoS specification language. The instrumentation of these components is being carried out by inserting probes to send timestamps to the resource manager. This will enable the resource manager to monitor their QoS performance in real-time and will allow the measurement of the amount of CPU resources required by the ITOS application programs.

The DeSiDeRaTa adaptive resource manager will provide the features of dependability and reliability for the ITOS system. The resource manager will achieve these benefits by continuously monitoring the dynamic real-time QoS performance of the ITOS system and maintaining it by performing necessary re-allocation actions whenever a QoS violation occurs. Further capabilities include the features of survivability and fault tolerance, by which, the resource manager will automatically restart any ITOS process or component that terminates. The DeSiDeRaTa resource manager provides a visual human computer interface (HCI) that displays the real-time QoS performance of the various dynamic paths of ITOS in terms of latency graphs. The resource manager HCI can also be used to move a monitored ITOS processes between multiple hosts to address a QoS violation and to maintain the required QoS levels.

The ITOS system was originally designed to run on a single host at any instant and work is being carried out to enable the distribution of selected ITOS components across multiple hosts for achieving better QoS performance. Currently, the resource manager does not control the ITOS programs that are directly started by the ITOS system. The integration of RM with ITOS has led to the discovery that the ability to track processes that are not initiated by the RM will be beneficial. This functionality will be added to the RM that will further enhance its capability to control dynamic real-time systems like ITOS.

To demonstrate the effectiveness of the adaptive resource management approach for ITOS and to show the aforementioned features in the ITOS system, a scenario was developed:

- Auto start/stop of ITOS: The entire ITOS system will be automatically started/stopped by the RM.
- Instrumentation of ITOS components: The ITOS components – *tlm_client* (telemetry system), *frame sorter* and *pkt_extract* (frame sorter subsystem) and *dsp_mnepage* (display subsystem) will be instrumented to send timestamps to the RM.
- QoS monitoring and display: The QoS of the
 - telemetry path – *frame input @ vc_sorter @ output @ tlm_client @ ODB*
 - frame sorter path – *frame input @ vc_sorter @ pkt_extract @ output*
 - display path – *tlm_client @ ODB @ dsp_mnepage @ user*will be monitored and the QoS display of their real-time performance in the RM HCI, through the latency graphs, will be shown.
- Survivability of ITOS: RM providing fault tolerance to ITOS components by reloading them whenever they terminate.
- Distributed ITOS components: Relocation of the *frame sorter* and *dp_server* processes to a different host to prove that the ITOS system components can be distributed across multiple hosts.
- QoS violation and RM reallocation: The tactical load to the telemetry system will be increased by the increase of the rate of flow of the input telemetry data until a QoS violation occurs. The RM HCI will be used to view the sequence of actions (reallocation of the ITOS components) that the resource manager takes to restore the QoS.

V. CONCLUSIONS AND FUTURE WORK

Future spacecraft systems are expected to work in dynamic environments with dynamically varying workloads. Hence, there is a necessity for real-time software control to realize these types of space systems. This paper presents the DeSiDeRaTa adaptive resource management strategy that is being evolved to accommodate the dynamic characteristics mentioned above. The dynamic and distributed attributes of ITOS are being met by DeSiDeRaTa's use of middleware mechanisms and a framework for reasoning about the real-time performance of distributed application systems. The

integration of ITOS with the resource manager is explained and a demonstration scenario that shows the effectiveness of the adaptive resource management approach for ITOS is presented.

Presently, the telemetry system, frame sorter and the display subsystems have been integrated with DeSiDeRaTa. This integration process will be extended to include the rest of the ITOS systems – STOL, command and event. Dynamic scenarios, challenging enough to force resource reallocations, will be run and the QoS performance in each case will be recorded. Several assessment metrics will be gathered to assess the quality of the adaptive resource management strategy that has been implemented. The improvements in the QoS per reallocation action will be measured. A ground based test bed to provide the early evaluation of dynamic systems without the expense of deploying spacecraft will be achieved. An additional benefit is that the ITOS system will become distributed, survivable and scalable.

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